Title: Intraocular pressure responses to four different isometric exercises in men and women

Running head: Isometric exercise increases intraocular pressure

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Abstract

Significance: The performance of resistance exercise has evidenced to induce abrupt intraocular pressure changes, which has been linked to the onset and progression of glaucoma. We found that four different isometric resistance exercises lead to an instantaneous and progressive intraocular pressure elevation, with these changes being independent on the type exercise.

Purpose: The impact of physical exercise on intraocular pressure has demonstrated to be dependent on exercise type and intesity, as well as individuals´ characteristics. In this study, we aimed to explore the influence of the load, exercise type and participant´s sex on the intraocular pressure behaviour during a 2-min isometric effort.

Methods: Twenty-eight physically active collegiate students performed 2-minutes of isometric exercise in the military press, biceps curl, leg extension and calf raise exercises against two different loads (high-load and low-load). Intraocular pressure was measured by rebound tonometry before, during (semi-continuos assessment [24 measurements]), and after 10 seconds of recovery in each of the eight (4 exercises x 2 loads) conditions.

Results: We found a statistically significant effect of load ($p<.001$, $\eta_p^2=0.906$), with greater intraocular pressure values when performing the isometric exercises against heavier loads. There was a positive intraocular pressure rise during the execution of isometric exercise in the high-load condition, returning to baseline levels after 10 seconds of passive recovery. The exercise type and participant´s sex did not reveal statistically significant differences ($p=.326$ and $p=.558$, respectively).

Conclusions: Our data evidenced an instanteneous and progressive intraocular pressure rise during the execution of isometric exercise leading to muscular failure, regardless of the exercise type and participant´s sex. After exercise, intraocular pressure rapidly retuned to baseline levels (within 10 seconds). The inclusion of glaucoma patients in future studies is guarranteed.

Keywords: resistance training; exercise physiology; ocular health; glaucoma management.

Intraocular pressure responses to four different isometric exercises in men and women

Introduction

The regular practice of physical activity is associated with an increase in life expectancy and a decrease in the development of mental conditions (e.g., depression, dementia or anxiety).[1,2] Recently, eye care specialists have begun to investigate the effects of physical exercise on ocular health, aiming to identify the most pertinent exercise programs for subjects with different ocular conditions.[3–5] Within the range of ocular conditions that have attracted researchers´ attention, glaucoma is undoubtedly the most investigated visual condition due to both its high prevalence worldwide and the severity of the symptoms (irreversible vision loss).[6,7] The main variable related to the onset and progression of glaucoma is the intraocular pressure, which is defined as the pressure exerted by the aqueous humour against the outer layer of the eye.[8] Training programs should attempt to reduce baseline intraocular pressure values and avoid intraocular pressure peaks during exercise because these are the two most important factors for the management of glaucoma.[9]

Numerous studies have found acute intraocular pressure changes during or immediately after the performance of different physical efforts.[10–15] For example, resistance training against heavy loads acutely increases intraocular pressure values,[16] while running at different intensities seems to decrease intraocular pressure.[11,12] The impact of resistance training on intraocular pressure has been tested for dynamic and isometric exercises, being the intraocular pressure increments generally higher for the isometric exercises.[14,17] The results of previous studies suggest that performing resistance training against heavy loads, and mainly the execution of isometric exercises, should be discouraged for individuals at high risk for glaucoma onset or progression.

It is known that the changes in intraocular pressure during resistance training depend on several factores such as the magnitude of the load, participants´ fitness level and sex, and the type of exercise.[13,18,19] Vera and colleagues reported a positive association between the intraocular pressure rise and the load lifted during the dynamic bench press and back-squat exercises.[18] Regarding the exercise type, there is evidence suggesting that dynamic resistance training exercises involving larger muscle mass and the upper-body promote greater intraocular pressure rises compared to exercises involving smaller muscle groups and the lower-body, respectively.[13] Studies comparing the acute changes of intraocular pressure between men and women have reported contradictory results. Whereas women exhibited a greater intraocular pressure reduction during a high intensity interval training protocol,[11] the changes in intraocular pressure values during the execution of four different dynamic resistance training exercises (back squat, military press, biceps curl, and calf raise) were comparable for men and women.[13] In addition, it is unknown whether the the type of exercise and participants´sex may modulate the intraocular pressure behaviour during different isometric exercises. Therefore, it would be important to assess the intraocular pressure responses to isometric exercises that involve different amounts of muscle size and body parts in men and women.

To address the limitations previously mentioned, the intraocular pressure of healthy men and women was semi-continuously measured for 2 minutes during 4 isometric exercises (military press, biceps curl, leg extensions, and calf raises) performed against 2 loading conditions. Therefore, the main objective of the present study was to elucidate whether the intraocular pressure behaviour during a 2-minutes isometric effort is affected by (i) the magnitude of the load, (ii) the type of exercise, and (iii) the participant's sex. Based on previous findings, we hypothesized that (i) the use of greater loads would promote a higher intraocular pressure rise,[18] (ii) exercises performed with the upper-body involving large muscle groups would lead to greater intraocular pressure values,[13] and (iii) the lack of studies comparing the differences between men and women on the intraocular pressure responses to isometric exercises did not allow us to formulate any specific hypothesis.

Methods

Participants

Twenty-eight physically active collegiate students took part in this study (Table 1). All participants

	Total sample (n =28)	Men (n = 14)	Women (n = 14)
Anthropometrical characteristics			
Age (years)	22.4 ± 2.1	21.8 ± 2.1	23.0 ± 2.1
Height (cm)	172.4 ± 6.8	176.9 ± 5.6	167.8 ± 4.6
Body mass (kg)	67.6 ± 11.1	77.1 ± 5.7	58.2 ± 5.7
Loads applied			
Military press (kg)	14.9 ± 3.4	17.6 ± 1.8	12.2 ± 2.4
Biceps curl (kg)	10.0 ± 3.0	11.8 ± 2.4	8.2 ± 2.4
Leg extensions (kg)	22.6 ± 5.2	26.5 ± 3.3	18.6 ± 3.7
Calf raises (kg)	48.8 ± 12.1	55.4 ± 13.0	41.7 ± 5.5

had at least 2 years of resistance training experience and were familiar with the exercises used in this study. We excluded participants with any physical limitation that could compromise tested performance, as well as those with a history of any ocular or cardiovascular disease or surgery. Participants were not taking any medication that could affect eyes physiology and women were not assessed during the menstruation phase. The study followed the guidelines of the Declaration of Helsinki and was approved by the Institutional Review Board.

Table 1. Mean ± standard deviation of anthropometrical characteristics and isometric exercise loads of all the participants included in this study.

Table 1 near here

Experimental design

We used a repeated measures design to explore the cummulative effect of four isometric exercises on intraocular pressure. Participants attended to the laboratory on two occasions separated by 48-72 hours, which were scheduled at the same time of the day (± 1 hour) in order to avoid the influence of circadian variations on physical performance.[20] In the first session, they read and signed the consent form, and filled-in the demographic questionnaire. Participants were also instructed how to perform the different isometric exercises and the maximal load that participants could hold for approximately 2 minutes was determined (see testing procedure below). The second session consisted of eight sets

(4 exercises [military press, biceps curl, leg extensions and calf raise] x 2 loads [heavy load: load that could be hold for 2 minutes; light load: no additional load was applied]). Each set was separated by 10 minutes of passive rest. The order of the exercises and loads was randomised. Intraocular pressure was measured before exercise, during the 2-minutes of isometric effort (continuos measurement), and after 10 seconds of recovery (**Figure 1**). Both experimental sessions were conducted under controlled environmental conditions (∼22°C and ∼60% humidity), and participants were not allowed to drink or eat during the experiment.

Isometric exercises

The maximum load that participants could hold for approximately 2 minutes in an isometric condition was determined in the first testing session for all exercises (military press, biceps curl, leg extension, and calf raise). After a warm-up consisting of 5 minutes of jogging and joint mobility exercises, an incremental loading test was performed to determine the maximum load. The initial load corresponded to the 75% of the load that participants believed that they could hold for 2 minutes. This load was progressively increased in agreement between the participant and an experienced researcher. To minimize fatigue, participants were instructed to stop the exercise when they or the researcher perceived that the applied load could be hold for more than 2 minutes. Three minutes were implemented between successive sets. The average number of sets needed to reach the maximum load was 2.4 ± 1.2 for the military press, 1.8 ± 1.5 for the biceps curl, 2.8 ± 1.6 for the leg extension, and 2.5 ± 1.5 for the calf raise. The maximum load was determined at the same positions that were used for the measurement of intraocular pressure during session 2 (see **Figure 1**): (I) *military press*: participants seated with the back supported by a bench reclined 5º respect to the vertical direction and the elbows flexed with the hands positioned at the height of the chin; (II) *biceps curl*: upright position with elbows flexed at 90º; (III) *leg extension*: participants seated with the back supported by a bench reclined 15º respect to the vertical direction and the knees fully extended; and (IV) *calf raise*: upright position with hips, knees, and ankles fully extended. All exercises were performed bilaterally, and participants were asked to maintain a constant breathing pattern during exercise.

Figure 1 near here

Intraocular pressure assessment

An Icare rebound tonometer (Icare, TiolatOy, INC. Helsinki, Finland) was used to assess intraocular pressure at the different time points. The main advantages of this apparatus include that it is portable and hand-held, allows a rapid acquisition of intraocular pressure measures, it is very well tolerated by patients, and does not require the use of topical anaesthesia.[21] Following the manufacturer's instructions, participants were instructed to look at a distant target while performing the isometric exercise and intraocular pressure was continuously measured against the central cornea by an experienced optometrist (JV or BR). Intraocular pressure values were vocalized to a research assistant for data logging, obtaining a minimum of 24 measurements during the isometric effort (range of data points from 24 to 28 measurements).

The Icare tonometer cannot acquire intraocular pressure measurements at exact time intervals and due to the manual logging of the values we lacked exact measurement timestamps. For this reason, we devised a process to overcome these technical restrictions and obtain a set of equally distributed values at regular intervals with exact timestamps that we describe in the data processing subsection. A baseline intraocular pressure was measured before each exercise, and we obtained a recovery measurement 10 seconds after the exercise. We always measured the right eye. The same procedure for intraocular pressure assessment was conducted in a recent study.[22]

We were able to semi-continuously measure intraocular pressure due to the inherent characteristics of the tonometer and the exercise (static exercise with neutral neck position). This is the main novelty of this study compared to previous investigations, where the effects of different types of strength or endurance exercises were evaluated using a simple pre/post design.[14,16,18,19,23]

During the 2-minutes isometric exercise, intraocular pressure values were acquired in a continuous fashion.

Data processing

To overcome the timestamping issue and the lack of automatic logging restrictions of the rebound tonometer, we obtain a set of equally distributed intraocular pressure values at regular intervals using the following procedure based on multi-rate digital signal processing. Specifically, we use sample rate conversion to adjust the sampling rate of the discrete sampled signal (i.e., the intraocular pressure signal) in order to obtain a new discretised version of the original continuous signal at a different rate.[24,25] When measuring intraocular pressure using the rebound tonometer, we sampled the continuous intraocular pressure function at slightly irregular intervals. The values measured were the values of the intraocular pressure function at those moments-in-time. But since the function is continuous, when intraocular pressure values rise and fall between two pressures, intraocular pressure will always take all intermediate values between these two pressures. As such we can reconstruct the intraocular pressure function from the sample measurements by treating the obtained samples as geometric points and then creating the necessary new points by polynomially interpolating those values to obtain 24 discrete values for the 2-minute period, i.e., every 5 seconds.

Statistical analysis

First, we applied a mixed analysis of variance (ANOVA) to intraocular pressure values considering the exercise type (military press, leg extensions, biceps curl, calf raises), load (low and high), and point of measure (baseline, 1 to 24, and recovery [a total of 26 measurements]) as the within-participants factors, and sex (men vs women) as the between-participants factor. Additionaly, linear regression analyses, considering the 24 measurements taken during the 2-minutes isometric efforts, were carried out in order to assess the intraocular pressure behaviour during exercise. The magnitude of the differences was reported by the partial eta squared (η_p^2) and, statistical significance was set at an alpha level of .05.

Results

The first set of analysis evidenced a statistically significant effect of load ($F_{1, 25} = 257.39$, $p < .001$, $\eta_p^2 = 0.906$), point of measure ($F_{25, 625} = 20.57$, $p < .001$, $\eta_p^2 = 0.443$), whereas no differences were observed for the exercise type ($F_{3, 75} = 1.17$, $p = .326$) and sex ($F_{1, 25} = 0.30$, $p = .588$). There were also statistically significant differences for the interactions *exercise type x sex* ($F_{3, 75} = 3.76$, $p = .014$, $\eta_p^2 = 0.126$), *exercise type x point of measure* ($F_{3, 75} = 2.13$, $p < .001$, $\eta_p^2 = 0.08$), *load x point of measure* ($F_{25, 625} = 23.68$, $p < .001$, $\eta_p^2 = 0.476$), and *exercise type x load x point of measure x sex* ($F_{75, 1875} = 1.34$, $p = .030$, $\eta_p^2 = 0.050$). The rest of interaction did not reach statistical significance (all p-values > .05) (**Figures 2 and 3**).

In the high-load condition, the intraocular pressure behaviour showed a fairly linear and positive increase as a function of time-on-task during isometric effort, with Pearson correlation coefficients of 0.94, 0.80, 0.74, and 0.57 for the military press, biceps curl, leg extension, and calf raises exercises, respectively.

Figure 2 near here

Figure 3 near here

Discussion

The current study was designed to assess the influence of the load, exercise type and participants' sex on the intraocular pressure changes induced by isometric exercises. Our data revealed that performing 2-minutes of isometric exercise leading to muscular failure (high-load condition) promoted a progressive intraocular pressure rise, regardless of exercise type and participants' sex. Namely, the military press, biceps curl, leg extensions, and calf raise exercises caused a comparable increment of intraocular pressure levels during the high-load condition (average intraocular pressure rise of ~ 25%, range: 22% to 26%) for both men and women. When exercise ceased, intraocular pressure returned to baseline levels in the subsequent 10 seconds. This result highlights that valuable information could be missed in experimental studies using pre/post designs and, thus, intraocular pressure assessment during exercise should be recommended. The outcomes of this study may have important implications for the management of ocular conditions in which maintaining stable intraocular pressure levels are desirable, especially for subjects at high risk for glaucoma onset or progression.

During the execution of dynamic resistance training exercises, the intraocular pressure changes have been shown to be dependent on the type of exercise performed. For example, a recent investigation reported a higher intraocular pressure rise during the bench press compared to the back squat when both exercises are performed against the same relative load.[19] Similarly, Rüfer et al.[14] found a significant intraocular pressure rise after performing 20 repetitions with the butterfly machine, whereas the execution of 20 repetitions during the leg curl exercise did not induce a significant change in intraocular pressure. The results of the present study provide additional evidence highlighting that intraocular pressure changes associated with isometric exercise are not exercise-dependent, at least for the exercise types included in this study. It should be noted that we chose exercises involving a considerable amount of muscle mass (military press or leg extensions), however, other exercises such as the bench press or back-squat may be more physically demanding and could promote a more abrupt intraocular pressure response. Indeed, recently published data from our laboratory suggest that the execution of 1-minute isometric squat exercise leading to muscular failure promoted an intraocular pressure rise of approximately 8 mmHg at the end of the 1-min effort, whereas the greatest intraocular pressure increment found in the current study was of approximately 5 mmHg.[22] Taken together, it seems reasonable to discourage the execution of very challenging and prolonged isometric efforts when intraocular pressure fluctuations are undesirable (e.g., glaucoma patients) because they have shown to provoke a meaningful, instantaneous and cumulative intraocular pressure rise. It should be noted that the average IOP rise observed in this study may be comparable with the nocturnal elevation of IOP occurring in healthy subjects (2 to 6 mmHg).[26,27] Therefore, the possible detrimental effects of the IOP rises caused by resistance training in healthy individuals require further investigation.

There are controversial results regarding the sex-related differences in intraocular pressure responses to resistance training. For example, two studies have shown that males and females have similar intraocular pressure responses to different dynamic resistance training exercises,[13,28] whereas Vera and colleagues[22] observed that men had a more accentuated intraocular pressure rise in comparison to women, although these differences only reached statistical significance during the last seconds of an isometric squat exercise performed until muscular failure. In this study, our results demonstrated that the intraocular pressure response to isometric exercise does not systematically differ between men and women. However, in the military press exercise, the differences were considerable (ES [90% confidence intervals] = 1.62 [0.73 – 2.43], with men exhibiting a more accentuated intraocular pressure increase in comparison to women. Of note, previous studies have commonly considered 1-minute of isometric effort,[22,29] showing a linear increase of intraocular pressure over time. The results of the present study highlight that the intraocular pressure is progressively increased until at least 2 minutes. However, it should be noted that during the execution of the high-load condition the intraocular pressure rise in the four exercises after the first minute was 22% (i.e., last point of measure of the first minute), whereas the percentage of intraocular pressure increment when considering the last point of measure of the 2-minutes effort was 29%. This analysis shows that the slope of the intraocular pressure rise during isometric exercise is slower when considering longer periods of time. Notably, when leading to muscular failure during an isometric effort, 1-minute of isometric squat exercise promoted an intraocular pressure increment of 59%.[22] In order to test the influence of exercise duration on intraocular pressure, the same isometric exercise should be tested when the time under tension is different (i.e., 1 vs 2 minutes), but matching the level of effort (e.g. both exercises leading to muscular failure).

Current limitations and implications for future research

The current investigation is not exempt of limitations, and they must be acknowledged. First, our experimental sample consisted of healthy and physically active collegiate students, and the main implications of our findings are targeted at glaucoma patients or those at risk of glaucoma. Therefore, the external validity of the present findings in glaucoma subjects needs to be addressed in future investigations. Second, we tested the intraocular pressure changes during four different isometric exercises, however, the effects of isometric efforts during other exercises, including those performed while adopting head down position (yoga or crossfit) or lying face down (abdominal planks), should be assessed. Third, fitness level has demonstrated to play a mediating role on the intraocular pressure responses to physical exercise,[19,30] and thus, it is our hope that future studies will assess whether intraocular pressure changes induced by isometric exercise are dependent on participants' fitness level. Lastly, the practice of physical exercise has numerous health benefits,[31] including a neuroprotective effect in different eye disorders.[5] Based on this, it is necessary to determine the most beneficial physical activity in order to preserve the ocular health. In this regard, isometric resistance training may not be the most pertinent type of physical exercise, although it is clear that the health benefits associated with physical activity indicate that adopting a sedentary behaviour needs to be avoided.

Conclusions

The execution of 2-minutes isometric exercises leading to muscular failure promotes an instantaneous and progressive intraocular pressure rise in healthy adults, being these changes independent of the tested exercise (military press, leg extensions, biceps curl, calf raises). When physical effort ceased, intraocular pressure rapidly returned to baseline levels (within 10 seconds). Overall, there were no meaningfull differences between men and women in intraocular pressure responses to physical exercise with the only expection being the military press exercise in which men showed a greater intraocular pressure rise in comparison to women. The present outcomes may be of interest for eye care specialists, since the performance of isometric efforts should be discouraged when stable intraocular pressure levels are desirable, especially for individuals at high risk for glaucoma onset or progression. The inclusion of glaucoma patients in future investigations is needed to explore the generalizability of the current findings.

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Figure legends

Figure 1. Schematic illustration of the experimental procedure (from left to right: military press, biceps curl, leg entension, and calf raise). The same protocolol was repeated in eight different occasions (4 exercises x 2 loads), and the order of the exercises and loads was randomized. A 10 minutes break was given between two sets. The recovery measurement of intraocular pressure was taken 10 seconds after the exercise cessation.

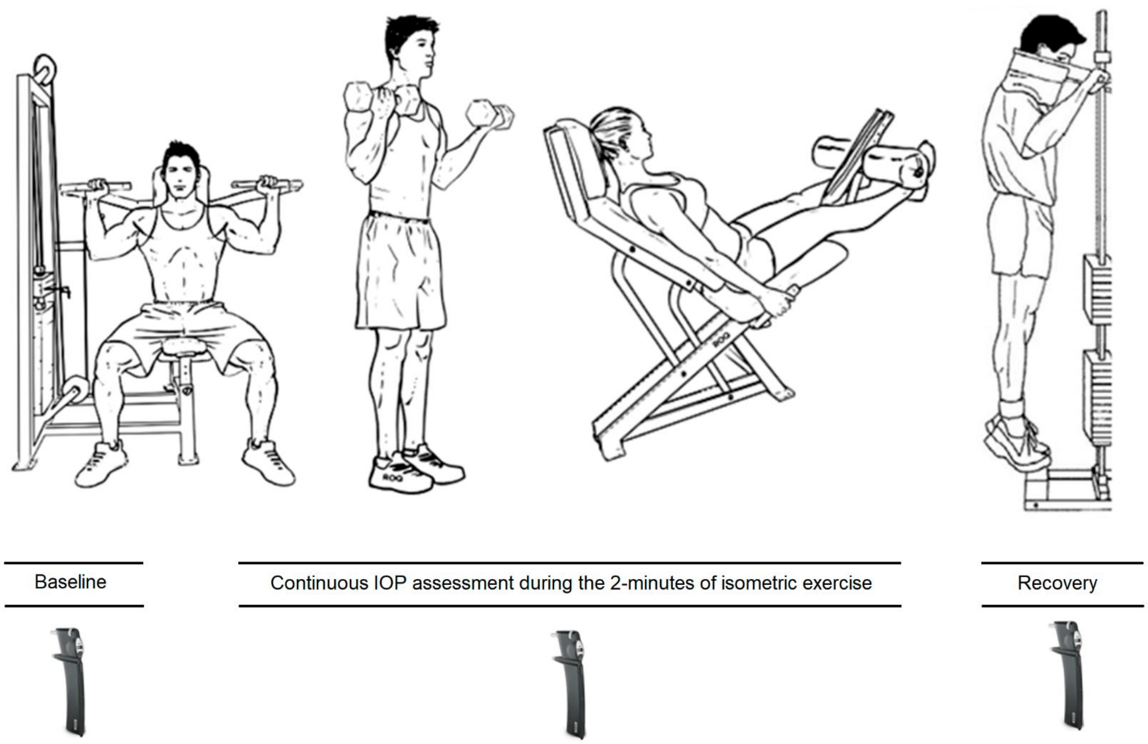

Figure 2. Effects of performing 2-minutes of isometric military press (panel A), biceps curl (panel B), leg extensions (panel C), and calf raises (panel D) against the maximum load that participants could hold for approximately 2 minutes in an isometric condition (high-load) and without applying any additional load (low-load) on intraocular pressure. The recovery (REC) value represents the

measurement taken 10 seconds after the exercise cessation. Error bars show the 95% confidence intervals.

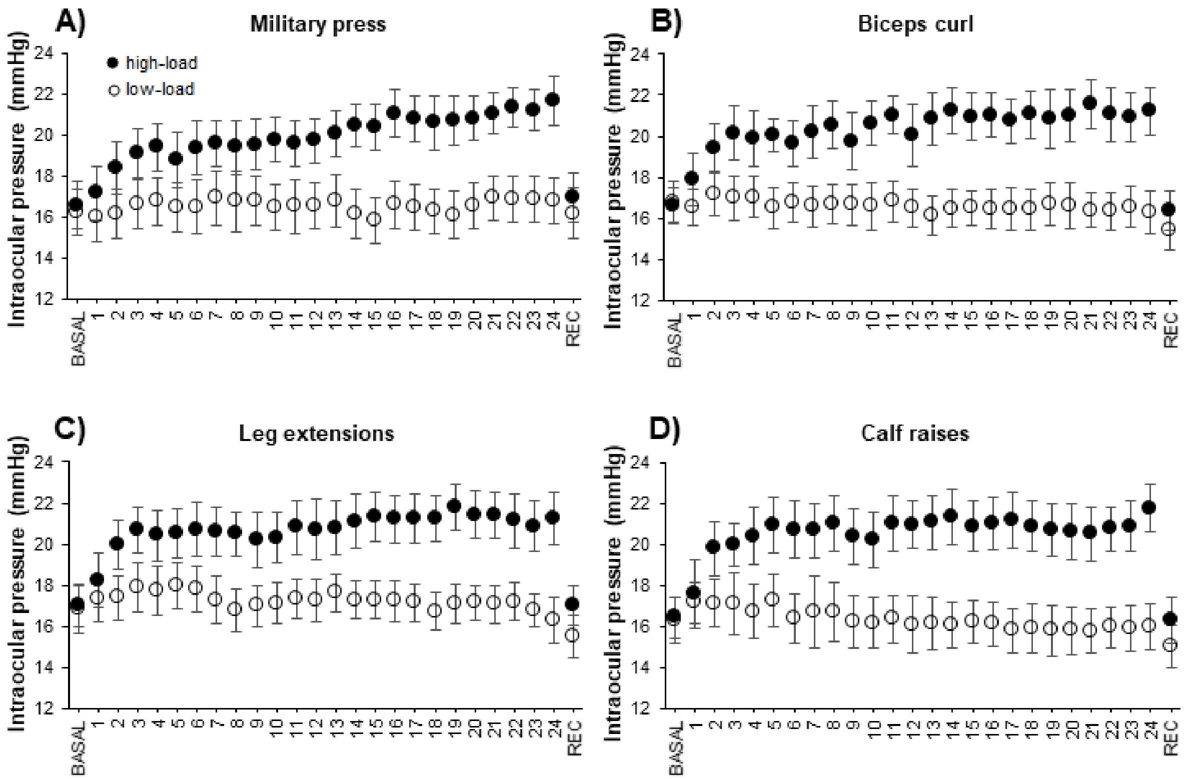

Figure 3. Standardized differences (Cohen´s d effect size) with the corresponding 90% confidence intervals in the intraocular pressure changes (average value of the 2-min isometric efforts in the low and high-load conditions) between men and women when performing the four different isometric exercises.